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Trace Metal Concentration in the Liver Tissues of Four Fish Species from Alexandria Coastal Waters, Egypt.

تركيز الفلزات الشحيحة في أنسجة الكبد لبعض أنواع الأسماك من سواحل الإسكندرية، مصر

وفيقة محمد أبو النجا و محمد كمال زكي الديب

Wafeqa Mohamed Aboul Naga & Mohamed Kamal Zeki Al Deep

National Institute of Oceanography and Fisheries

Qayet Bey, Alexandria, Egypt.

Abstract: Zinc (Zn), Iron (Fe), Manganese (Mn), Copper (Cu), Nickel (Ni), Lead (Pb), Cadmium (Cd) and Chromium (Cr) metals were detected in the liver tissues of four fish species: planktonivorous Round Sardinella *(Sardinella aurita)*, herbivorous Marbled spine foot *(Siganus rivulatus)* and the omnivorous Two banded sea bream *(Diplodus vulgaris)* and carnivorous sparid fishes Bogus *(Boops boops)*, which are subjected to various types of terrestrial fallout, and caught from the coastal waters of Alexandria. Results indicate that these metals occur at high levels. Selecting liver for this study, a significant organ in toxicological processes including storing, metabolizing and elimination of body toxins, was based on its situation as a detoxification center and its important function as a site of minimizing pathological effects induced by contaminants. A pronounced increase in the liver content of tested fish species from unessential contaminant metals such as Lead (Pb), Nickel (Ni), Chromium (Cr) and Cadmium (Cd) was noticed in spite of their limited regulation and slow excretion from marine organisms. The common biologically essential elements: Copper (Cu), Iron (Fe), Zinc (Zn), and Manganese (Mn), which are under haemostatic control were found in relatively higher values. Good correlation of some liver metal concentrations such as Copper (Cu), Lead (Pb), and Chromium (Cr) was found with the corresponding lipid contents. In addition, the liver metal accumulation from the ambient surrounding waters was calculated for the four fish species studied. A clear relationship was found between biomagnifications of trace metals in the liver tissues and their feeding habits.

Keywords: Alexandria, coastal waters, fish species, liver tissues, concentration, metals, lipid, biologically essential.

المستخلص: تستهدف الدراسة إلى تقدير تركيز العناصر الفلزية، الزنك (Zn) ، والحديد(Fe) ، والمنجنيز (Mn) ، والنحاس (Cu) والنيكل (Ni) ، والرصاص (Pb) ، والكادميوم (Cd) ، والكروميوم (Cr) في أنسجة الكبد، لأربعة أنواع من الأسماك المعرضة لمختلف الأنواع من التصرفات الأرضية، وهي الأنواع آكلات البلانكتون (السردين,*Sardinella aurita*) ، وآكلات الأعشاب (البطاطا *Siganus rivulatus*)، والأنواع آكلات المواد الحيوانية والنباتية معا(المترممة *Diplodus vulgaris*)، والأنواع آكلات اللحوم؛ (الشرغوش والموزه *Boops boops*) . وآلتي قد تم اصطيادها من سواحل الإسكندرية في مصر. أوضحت النتائج وجود هذه العناصر الفلزية بتركيز عالي، وتحديدا في أنسجة الكبد من الأسماك عينة الدراسة، والتي قد كان اختيارها ، لأنها العضو المميز للتخلص من السموم وتخزينها، والقيام بعمليات الأيض الغذائى، فضلا عن وظيفتها الأهم كموقع لتقليل التأثيرات المرضية الناتجة من تراكم الملوثات. يلاحظ بوضوح زيادة العناصر الفلزية غير الأساسية مثل الرصاص (Pb) ، النيكل (Ni) ، الكروميوم (Cr)، والكادميوم (Cd) ، علي الرغم من دورها المحدود وإفرازها البطيء من الكائنات البحرية. أما العناصر الفلزية الضرورية بيولوجياً للأسماك، وآلتي تخضع للتحكم من قبل الدورة الدموية، مثل النحاس (Cu) ، والحديد (Fe) ، والزنك (Zn) ، والمنجنيز(Mn) ، فقد وجدت بقيم عالية نسبياً. كما وجد معامل ارتباط جيد بين تركيز بعض العناصر مثل النحاس (Cu) ، والرصاص (Pb) ، والكروميوم (Cr) مع محتوى أنسجة كبد الأسماك من الدهون. أما عن معامل التراكم البيولوجي لمحتوى أنسجة كبد الأسماك من الفلزات الشحيحة، مقارنة مع محتوى الوسط المائي المحيط من الفلزات، يلاحظ علاقة واضحة بين التكبير الحيوي للفلزات الشحيحة في أنسجة كبد الأسماك وعاداتها الغذائية.

كلمات مدخليه: الإسكندرية، سواحل، أسماك، أنسجة الكبد، تركيز، فلزات، دهون، تراكم بيولوجي .

Introduction

The Mediterranean Sea, a huge basin, semi-closed from the global oceans, is subjected to the impacts of heavy discharges of pollutants from numerous industrial processes, particularly in Spain, France, Italy and Egypt, where there are big centers of mass production. In Egypt, Alexandria coastal water is comparably considered one of the major pollution-stressed sites in the Mediterranean. The problem is identified as industrial and agricultural-derived pollutants on the one hand and sewage-derived pollutants from the other. The area is between (Lat.31° 08` to 31° 26` North) and (Long

.29° 47` to 30° 06` East) and extends for about (38 km) from Agami (West) to Abu-Qir Head (East). Over (183 x 10^6 m^3 $year^{-1}$ of untreated sewage and waste waters are discharged into the coastal waters of Alexandria. In addition to many industrial effluents, there is also as well as agricultural runoff (brackish water, 2.57 x 10^9 m^3 $year^{-1}$) from El-Umum drain, which discharges its waters into Lake Mariut. The contaminated waste water of the lake is consequently disposed into the sea through El-Mex Pumping Station.

Fish are widely used as sentinels of contamination in the aquatic environment. The levels of heavy metals accumulated by marine organisms are functions not only of water quality, but also of seasonal factors such as; temperature, salinity, diet, spawning and individual variations (O'Dell and Campbell, 1971). Muscle (flesh) is the tissue most commonly tested because of the implications it carries for human consumption and health risk. However, the liver is often recommended because it concentrates many contaminants at high orders of magnitude above muscle concentrations (Schroeder *et. al.*, 1970). It has an important role in contaminant storage, redistribution, detoxification and biotransformation, in addition to its role as an important site of pathological effects induced by contaminants.

Fish livers are used as the target tissue for monitoring purposes of organic and inorganic contaminants. Regarding these bases, trace metal contamination is considered to be of particular interest. Some of them are essential for growth but can be toxic above certain concentration levels and others are highly toxic even at very low concentrations. Comprehensive investigations of metal uptake in fish with respect to diet, water, and trophic status have shown that concentrations of metals are the result of a complex interaction of many factors (Williams and Giesy, 1978); (Wiener and Giesy, 1979); (Edwards *et. al.*, 2001).

Round sardinella, (*Sardinella aurita)* is a migratory species characterized by its filter feeding habits on phytoplankton, zooplankton (particularly copepods), while Bogus, (*Boops boops)* have a different feeding habit, varying between carnivorous and omnivorous. Marbled spine foot (*Siganus rivulatus)*, is a coastal fish feeding mostly on seaweed (Bianchi, 1985); (Aboul Naga, 1996), while Two-banded sea bream (*Diplodus vulgaris)* is an omnivorous species. (El-Nady 1981); (El-Rayis 1986); (El-Rayis *et. al.*1997) and (Mahmoud and Allam 2000) studied the levels of trace metals and the accumulation of some metals in the different organs of marine fish species of the Egyptian Mediterranean water.

Selection of these species was performed in summer 1995. They were choosen because of their known indication of heavy metals accumulation. They are common in the Alexandria region and are locally consumed as food of high commercial value. Determination of the bioconcentration of metals particularly, Iron (Fe), Zinc (Zn), Copper (Cu), Cadmium (Cd), Cromium (Cr), Manganese (Mn), Lead (Pb) and Nickel (Ni) in their liver tissues relative to the lipid content was undertaken. The uptake and accumulation of essential and nonessential metals in the different fish species are controlled not only by food, but also by other factors such as; water and other environmental conditions including periodicity of exposure to contaminants.

Materials and Methods

Round sardinella *(Sardinella aurita),* Bogus *(Boops boops),* Marbled spine foot, *(Siganus rivulatus),* and Two-banded sea bream *(Diplodus vulgaris)* were caught with trawl nets and fishing lines and frozen at (-18°C). Fish for metal analysis were thawed and the livers dissected. Samples were composite from different age groups. Dissected wet liver tissues were placed in cleansed (30 ml) (PFA Teflon) vials, weighed and digested with a mixture of nitric and perchloric acids. The levels of metals in liver were determined according to the method recommended by (FAO Technical Paper No. 158, 1976). Determination of Iron (Fe), Copper (Cu), Lead (Pb), Cadmium (Cd), Manganese (Mn), Zinc (Zn), Cromium (Cr) and Nickel (Ni) were performed with (Perkin Elmer 2380 Atomic Absorption Spectrophotometer) equipped with a deuterium background corrector. All metal concentrations Iron (Fe), Copper (Cu), Zinc (Zn), Manganese (Mn), Cadmium (Cd), Lead (Pb), Nickel (Ni) and Cromium (Cr) in the liver tissues of the fishes have been calculated on wet weight bases as (μg g^{-1}). Lipid content of the liver tissues is determined gravimetrically.

Results

Concentrations ($\mu g g^{-1}$ wet weight) of the (8 metals); Iron (Fe), Copper (Cu), Zinc (Zn), Lead (Pb), Manganese (Mn), Cadmium (Cd), Nickel (Ni) and Cromium (Cr) in the liver tissues of each fish species, as well as the lipid content (mg g^{-1} wet weight), are given in (Table 1). In general, all trace metal contents are relatively higher than in the muscle tissues.

Table (1): Trace metal concentrations in different fish species (μg g^{-1} wet weight) and the lipid content (mg g^{-1} wet weight).

Species	Iron (Fe)	Zinc (Zn)	Manga-nese (Mn)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Cadmium Cd)	Cromium (Cr)	Lipid
Round sardinellia *(Sardinella aurita)*	23.50	41.77	4.97	4.97	2.06	4.92	0.97	0.50	116
Marbled spine foot *(Siganus rivulatus)*	24.11	120.81	3.44	3.96	1.59	4.76	1.00	0.29	110
Bogus *(Boops boops)*	39.81	26.85	1.92	7.67	1.62	2.24	1.21	0.91	161
Two-banded sea bream *(Diplodus vulgaris)*	10.48	38.55	2.07	6.22	1.43	3.43	0.81	0.21	139

Discussion

According to (Table 1), liver tissues contained (1-20 times) more trace metals than muscle tissues (See, table 2) as previously detected by (Aboul-Naga 1996). Most tissues of chondrichthys (bony fishes) (kidney, brain, gills, gonads and spleen) have concentrations of the metals Arsenic (As), Cadmium (Cd), Copper (Cu), Mercury (Hg) and Zinc (Zn) similar to the muscle except for the liver which have higher concentrations (Windom *et. al.*, 1973). The order of abundance of trace metals in the liver tissues based on the average concentration has the following decreasing order:

[Zinc (Zn) > Iron (Fe) > Copper (Cu) > Lead (Pb) > Manganese (Mn) > Nickel (Ni) > Cadmium (Cd) > Chromium (Cr)].

This order follows the same sequence of occurrence in the muscle tissues, except for lead (Pb), and probably reflects the concentration of these metals in Alexandria water (Shriadah and Emara, 1992) and from the Red Sea coast of Yemen (Heba *et. al.*, 2001). The existing data on trace metals distribution in the various fish species from the Mediterranean Sea reveal that these metals are present in the liver tissue to a greater extent than in the muscle tissue. The relative accumulation is less pronounced for lead (Pb) (1.5 - 1.7 times). (Emara *et. al.* 1993) stated that trace metals accumulated in the muscle and bones of the fish species from the Mediterranean and Red Seas show the lowest ratios of trace metals concentration (bone/muscle) for lead (Pb) (1.1 - 2.5).

Bogus *(Boops boops)* has higher levels of Iron (Fe) (39.81μg g^{-1}), Copper (Cu) (7.67μg g^{-1}), Cadmium (Cd) (1.21 mg g^{-1}) and Chromium (Cr) (0.91 mg g^{-1}) in the liver tissues than other fish species studied. On the other hand, Bogus *(Boops boops)* liver tissue shows the high level of the lipid content (161 mg g^{-1}). Therefore, the increased concentration of Iron (Fe), Copper (Cu), Cadmium (Cd) and Cromium (Cr) in the liver of Bogus *(Boops boops)* may be related to their lipid-liver concentrations. This agrees with (Stacey *et. al.*1980) and (El-Shebly 2002), who found that Cadmium (Cd) has been identified as a potential lipid preoxidation inducer for (PUFA) which may be important for fish.

Table (2): Multiplication of liver metal concentrations relative to the muscle metal concentrations.

Species	Iron (Fe)	Zinc (Zn)	Manga-nese (Mn)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Cadmium Cd)	Cromium (Cr)
Round sardinellia *(Sardinella aurita)*	2.8	5.6	5.5	5.5	1.5	1.5	2.5	3.4
Marbled spine foot *(Siganus rivulatus)*	5.2	19.9	7.1	6.2	2.1	1.5	2.4	2.0
Bogus *(Boops boops)*	7.9	4.8	5.0	5.4	4.0	1.7	2.1	2.3
Two-banded sea bream *(Diplodus vulgaris)*	3.6	6.7	5.0	13.0	2.5	1.5	1.7	1.6

Calculation followed (Aboul-Naga 1996).

On the basis of the lipid weight of the liver, the concentration of Iron (Fe), Copper (Cu), Zinc (Zn), Manganese (Mn), Nickel (Ni), Lead (Pb), Cadmium (Cd) and Cromium (Cr) were calculated in (See, table 3). It appears from this table that Bogus *(Boops boops)* has an average concentration of (2 to 4 times) higher than Round Sardinella *(Sardinella aurita)* and Marbled spine foot *(Singanus rivulatus)* for Iron (Fe), Copper (Cu), Nickel (Ni), Cadmium (Cd) and Cromium (Cr), except Zinc (Zn), Manganese (Mn) and Lead (Pb) (Table 3).

Calculating the bioconcentration of the metals in the liver tissues of the fish species, relative to the ambient water using the data available on the concentrations of trace metals in Alexandria coastal waters by (Shriadah and Emara 1992), Bogus (*Boops boops*) may be proposed as a bioindicator (Table 4).

Table (3): Concentration of trace metals (μg g^{-1} wet weight) in the liver tissue of fish species based on lipid weight (mg g^{-1} wet weight).

Species	Iron (Fe)	Zinc (Zn)	Manga-nese (Mn)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Cadmium Cd)	Cromium (Cr)
Round Sardinellia *(Sardinella aurita)*	316	562	67	67	28	66	13	6.7
Marbled spine foot *(Siganus rivulatus)*	292	146	42	48	19	58	12	3.5
Bouge, *(Boops boops)*	1032	696	50	199	42	58	31	23.6
Two-banded sea bream *(Diplodus vulgaris)*	203	745	40	120	28	66	16	4.1

Calculation followed (Aboul-Naga 1996).

Table (4): Bioconcentration of trace metals in the liver tissue of fish species relative to the ambient water (x 10^3).

Species	Iron (Fe)	Zinc (Zn)	Manga-nese (Mn)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Cadmium Cd)	Cromium (Cr)
Round Sardinellia *(Sardinella aurita)*	13.5		40.9	10.7	64.4	140.4	7.3	38.3
Marbled spine foot *(Siganus rivulatus)*	12.5		25.6	7.7	43.7	122.6	1.00	20.0
Bogus (*Boops boops)*	44.1		30.5	31.8	96.6	123.5	1.21	134.9
Two-banded sea bream *(Diplodus vulgaris)*	8.7		24.4	19.2	64.4	141.03	0.81	23.4

Calculation followed (Shriadah and Emara 1992).

It was also noticed that the other sparid fish species Two-banded sea bream (*Diplodus vulgaris)* an omnivorous species highly bioconcentrated the non-essential metals; Nickel (Ni), Lead (Pb) and Cadmium (Cd) in addition to the other essential element Copper (Cu) as follows: (64.4), (141.0), (9.0) and (19.2 x103), respectively, with regard to its feeding habit (See, table 4). These pronounced high concentration factors of trace metals in the liver of the sparid fish species, omnivorous and carnivorous, actively moving fish based on the lipid weight, supports the suggestion that variable concentration of trace metals in the water and active swimming ability of fish may give the metal-exposed fish the chance of aclimatization and recovery (Tang and Garside, 1987). It is worth mentioning that high metal concentrations in the sea resulting from atmospheric deposition or continental contamination from mining or industrial wastes obligates the organism to withstand increased metal concentrations indefinitely (i.e., increased tolerance) if it is survive in the contaminated habitat. In addition, metal accumulation in tolerant or resistant organisms from heavily contaminated sites may represent a potential danger to consumers in higher trophic levels, including man (Duncan and Klaverkamp, 1983); (El-Nemr *et. al.*, 2003).

Correlation analysis between lipid content and concentration of trace metals in the liver tissues using standard linear regression gives a significant correlation at 95% confidence limit) for Copper (Cu) and Lead (Pb); (0.9880) and (-0.9877), respectively for all fish species (See, table (5)) and (Figure 1).

Table 5. Correlation matrix (significant level = 0.8114).

Metals	Iron (Fe)	Zinc (Zn)	Manga-nese (Mn)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Cadmium (Cd)	Chromium (Cr)	Lipid
Iron (Fe)	1								
Zinc (Zn)	-0.1372	1							
Manganese (Mn)	-0.1099	0.2604	1						
Copper (Cu)	0.4206	-0.8162	-0.7093	1					
Nickel (Ni)	0.2306	-0.1467	0.8758	-0.2842	1				
Lead (Pb)	-0.4460	0.6044	0.8658	-0.9517	0.5169	1			
Cadimum (Cd)	0.9983	-0.1117	-0.1543	0.4260	0.1762	-0.4686	1		
Cromium (Cr)	0.9243	-0.5049	-0.1920	0.6789	0.2617	-0.6185	0.9127	1	
Lipid	0.4415	-0.7194	-0.7194	0.9880	-0.4028	-0.9877	0.4555	0.6593	1

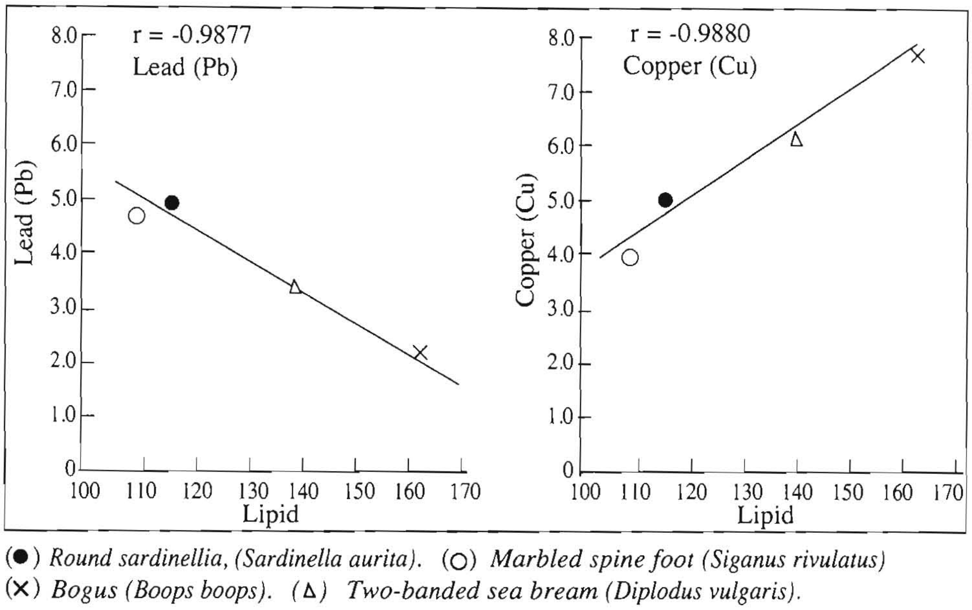

Figure (1): Relation between bioconcentrationof both lead (Pb) & copper (Cu) and lipid content in the liver tissues of fishes.

elevated metal concentrations (Tang and Garside, 1987).

Since fish are known to process the metal-binding protein metathionein (Friberg *et. al.*, 1971), a sequestering agent, detoxification of the heavy metals in fish liver may be by sequestration rather than elimination (Giesy and Wiener, 1977). The detected high metal contents in the studied fish, and their pronounced good condition factors:

Copper (Cu) concentrations increase in the liver tissues as the lipid content increases, while lead (Pb) concentration exhibits an opposite trend. The coefficient analysis reveals the presence of a good agreement between Cadmium (Cd), Cromium (Cr) and Iron (Fe); Nickel (Ni), Lead (Pb) and Manganese (Mn); Zinc (Zn) and Copper (Cu), but Nickel (Ni) is weakly correlated with these metals (See, table 5). This pattern indicates the existence of increasing tolerance and resistance of organisms resulting from

* Round sardinella *(Sardinella aurita) = (0.72)*
* Marbled spine foot *(Siganus rivulatus) = (0.9)*
* Bouge *(Boops boops) = (0.86)*.
* Two-banded sea bream,*(Diplodus vulgaris) = 1.45)*

These factors indicate that all of them are healthy, (Aboul-Naga, 1996) and (El-Deeb, 1998) are in a good agreement with the above assumptions.

Biomagnification of trace metals in the liver tissues showed a very significant relationship with the feeding habits of fishes (Figure 2).

It has been denoted that fish of mixed carnivorous and herbivorous habits Bogus *(Boops boops)* were clearly bioconcentrating most elements in their liver tissues, while herbivorous fish Marbled spine foot *(Siganus rivulatus)* was the species with minimum degrees of biomagnification. Fishes with mixed omnivorous and herbivorous feeding habits Two banded sea bream *(Diplodus vulgaris)* and planktonivorous fish, Round sardinella *(Sardinella aurita)* have nearly same degrees of magnitude for biomagnification of metals. This is due to the similar

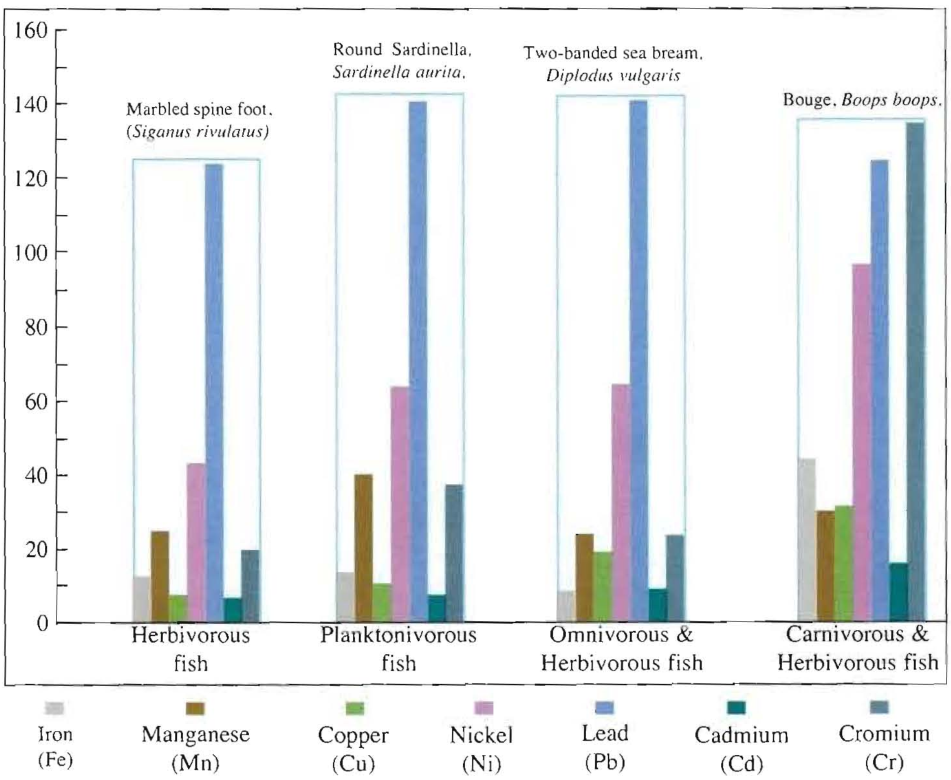

Figure (2): Relationship between biomagnification of trace metals in the liver tissues of fishes and their feeding habits.

sources of food; mixed omnivorous and herbivorous (marine plants and seaweeds, fragments of dead marine animals), planktonivorous (phyto and zooplankton, detrital materials of dead organisms). The pronounced high biomagnification degree of Lead (Pb) in all fish species is mainly related to the deposition of Lead (Pb) alkyls, particularly tetraethyl lead (Pb) which were used as anti-knock agents for raising the octane number of gasoline used in motor cars. The flow of Lead (Pb) alkyls through the atmosphere of Los Angeles area to the nearby coastal and open ocean was modelled by (Huntzicker *et. al.* 1975). Another convincing idea for the high biomagnification of lead (Pb) in liver tissues is due to the process of metal binding protein rather than the lipid content of liver, which gave a significant high negative correlation with lead.

References

Aboul-Naga, W.M. (1996) Winter and summer variations of trace metal contents in the muscle tissues of four fish species and other marine organisms in Alexandria coastal waters, Egypt. Journal of Egyptian German Society of Zoology. **21 (B):** 113-135.

Bianchi, G.W. (1985) FAO species identification sheets for fishery purposes. Field Guide to the Commercial Marine and Brackish Water Species of Pakistan, FAO, Rome.

Duncan, D.A. and Klaverkamp, J.F. (1983) Tolerance and resistance to cadmium in white suckers (Catostomus commersoni) previously exposed to cadmium, mercury, zinc, or selenium. Canadian Journal of Fish and Aquatic Science. **40:** 128-138.

Edwards, J.W., K.S. Edjvane, V.A. Boxall, M. Hamann and K.L. Soole (2001) Metal levels in Seston and Marine fish flesh near industrial and metropolitan centers in South Australia. Marine Pollution Bulletin. **42:** 389-396.

El-Deeb, M.K.Z. (1998) Studies on the transport and fluxes of aliphatic and aromatic petroleum hydrocarbons in Alexandria coastal waters and their levels in some marine organisms. (Unpub.) Ph.D. Thesis, Univ. of Suez Canal, p. 288.

El-Nady, F. (1981) Survey of some heavy metals in Alexandria waters and their effect on some marine animals. (Unpub.) Ph.D. Thesis, Univ. of Alexandria, p 317.

El-Nemr, A., El-Sikaily, A. and Khaled, A. (2003) Heavy metals concentration in some fish tissues from South Mediterranean waters, Egypt. Egyptian Journal Aquatic Biology & Fisheries. **7** (3): 155-172.

El-Rayis, O.A. (1986) Bioaccumulation of cadmium in plankton, bivalve, crustacean and in different organs of six fish species from Mex Bay, west of Alexandria. FAO Fish Report (**334**) Suppl: 50-56.

El-Rayis, O.A., Abuldahab, O., Halim, Y. and Riley, J.P. (1997) Levels of trace metals in some food chain organisms from El-Mex Bay, west of Alexandria, Egypt. ***In:*** Proceedings of the 7th International Conference on Environmental Protection is a Must. 20-22 May. 1997 Alexandria, Egypt.

El-Shebly, A.A. (2002) Effect of heavy metal pollution on growth hormone (GH) levels and growth rate of Oreochromis niloticus. Bulletin of National Institute of Oceanography & Fisheries, A.R.E. **28:** 191-199.

Emara, H.I., El-Deek, M.S. and Saber, N. (1993) A comparative study on the levels of trace metals in some Mediterranean and Red Sea fishes. Chemistry and Ecology. **8:** 119-127.

FAO (1976) Manual of methods in aquatic environment research. Part 3, FAO Technical Paper No. 158, FIRI/T, p. 158.

Friberg, L., Piscator, M. and Nordberg, G. (1971) Cadmium in the environment. CRC Press, Cleveland, OH, p.166.

Giesy, J.P.JR. and Wiener, J.G. (1977) Frequency distributions of trace metal concentrations in five freshwater fishes. Trans. American Fish Society. **106:** 393-403.

Heba, H.M.A., Al-Edreesi, M.A., Al-Saad, H.T. and Abdel-Moneim, M.A. (2001) Distribution of trace elements in tissues of five fish species collected from the Red Sea coast of Yemen. Bulletin of National Institute of Oceanography & Fisheries, A.R.E. **27:** 311-322.

Huntzicker, J.J., Friedlander, S.K. and Davidson, C.I. (1975) Material balance for automobile-emitted lead in the Los Angles Basin. Environtal Science Technology. **9:** 448-457.

Mahmoud, Th.H. and Allam, S.M. (2002) Heavy metals, protein and lipid concentrations in the muscles, liver and gonads of Boops boops. Journal of the Egyptian German Society of Zoology. **37 (A):** 225-242.

O'Dell, B.L. and Campbell, B.J. (1971) Heavy metal concentration in the sea. ***In:*** **R. Johnson, (ed.)** In Marine Pollution Academic Press, London. pp.185-302.

Shriadah, M.A. and Emara, H.I. (1992) The distribution of chromium, copper, cadmium and lead in areas of multi-polluting factors of Alexandria. Unesco.

Shroeder, H.A., Frost, D.V. and Balassa, J.J. (1970). Heavy metal contamination in the sea. ***In:*** **R. Johnson, (ed.)** Marine Pollution Academic Press, London. pp. 185-302 pp.

Stacey, N.H., Cantlina, L.R. and Klassen, C.D. (1980) Cadmium toxicity and lipid peroxidation in isolated rat hepatocytes. Toxicol. Appl. Pharmacol. **53:** 470-480.

Tang, Y. and Garside, E.T. (1987) Preexposure and subsequent resistance to lead in yearling Brook Trout, Salvelinus fontinus. Canadian Journal of Fish and Aquatic Science. **44:** 1089-1091.

Wafica M. Aboul-Naga (1996) Comparative study of trace metals accumulated in the muscle tissues of the most common and marketable sea food in Alexandria waters. International Journal of Environmental Health Research. **6:** 289-300.

Wiener, J.G. and Giesy, J.P. JR. (1979) Concentrations of Cd, Cu, Mn, Pb and Zn in fishes in a highly organic softwater pond. Journal of Fish Research Board of Canada **36:** 270-279.

Williams, D.R. and Giesy J.P. (1978). Relative importance of food and water sources to cadmium uptake by Gambusia affinis (Poecillidae). Environmental Research. **16:** 326-332.

Windom, H., Stickney, R., Smith, R., White, D. and Taylor, F. (1973) Arsenic, cadmium, copper, mercury and zinc in some species of North Atlantic fin fish. Journal of Fisheries Research Board of Canada **30:** 275-279.

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